MINING HEALTH AND SAFETY UPDATE

GROUND CONTROL

FROM THE EDITOR

The former U.S. Bureau of Mines Health and Safety Research Program has been transferred to the Department of Energy, and President Clinton's 1997 budget proposes that this program be assigned to the National Institute for Occupational Safety and Health (NIOSH). The Mine Health and Safety Program will be implemented through the Pittsburgh and Spokane Research Centers.

Mining Health and Safety Research Update will be issued periodically to apprise our readers of tangible research results and to expedite the transfer of new technologies. Each section of the Mining Health and Safety Research Update is planned to describe what's new or changed in relation to the current practices or technology in mines today.

To ensure that we meet the needs of those in mining, we will continually seek the views and comments of our readers. Enclosed with this Update is a business reply card. Please take a few minutes to respond. Your input will help us formulate the direction of our research. We are open to your contributions, suggestions, and questions at any time.

This first Update is directed toward developments in ground control, which is one of the most dynamic fields in mining. Changes in geology, mining conditions, and equipment can all have a significant impact on decisions related to mine design and operation. It is important for a research organization to stay in tune with such changes and to assess trends in these areas. In addition, we recognize that there are other interested organizations and groups who are contributors to and users of technological innovations in this area. As we see changes in the structure and operation of many of the organizations that are participants in this area, the ability to join together to solve the problems of today and tomorrow becomes imperative to all interests.

Inside - March 1996

LET US KNOW WHAT YOU THINK!

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The Pittsburgh and Spokane Research Centers are continuing health and safety research previously performed by the U.S. Bureau of Mines.

In Focus

Cable Bolts: A "New" Support

By Thomas P. Mucho

Cable bolts are emerging as the newest "twist" for roof support in U.S. underground coal mines. For decades cable bolts installed in underground metal mines in the United States and Canada used cement-based grouts for anchoring. The cement anchoring process, because of the time and expense for installation, made cable bolts impractical for use in coal mines. Today, the introduction of resin-anchored cable bolts provides a system more consistent with traditional U.S. coal mine roof bolting practices and requirements. Expectations are that the utilization of cable bolts for a number of U.S. mining applications will continue to expand, particularly in coal mining.

Cable bolt support technology, including hardware and anchorage systems, continue to evolve to satisfy U.S. mining industry requirements. Innovations have improved the ease and speed of cable bolt installation and the overall economy of cable bolting; efforts continue to expand these capabilities. For cables to be successfully implemented into the various ground control areas to which they seem suited, the range and mechanics of this support performance need to be fully understood. A variety of factors can affect cable system performance, including the mine geology and stress conditions. Variables that must be considered for cable installation include hole size; cable length (grouted length and free length); resin composition and formulation; the number, type, location, and relative size of cable anchors or buttons; and the use of resin dams/keepers. The health and safety research program, through cooperation with cable bolt and resin manufacturers and coal mining companies, is evaluating many of these key parameters through in situ testing at a number of coal mines, as well as at our Lake Lynn Laboratory near Morgantown, WV. Much of the early cooperative coal mine cable bolt testing involved western U.S. longwalls. Recently, we completed the first test of cable bolts at an eastern U.S. longwall site in southern West Virginia with a cooperating coal company (*see In the Field, p. 4*).

Manufacturers offer features that improve performance and/or ease of installation. Resin dam/keepers, devices intended to contain the resin in the anchor location, and metal "stiffeners" near the bolt head are examples. In addition, roof bolt resins are being formulated for use with cable bolts; some of these resins are specially mixed to ease installation.

Because of the coal industry's interest in injury prevention and safety and the potential support cost savings, the growth in use and development of cable bolt systems is expected to continue. Some advantages of cable bolts compared to traditional roof supports used in coal mines are detailed below.

- **Wide Secondary/Supplemental Support Applications -** Currently, most mines testing cable bolts use them in secondary and supplemental support applications, such as cribless longwall tailgates, bleeder entries, headgate support, long-life or critical openings, and timberless room-and-pillar secondary support applications. Cables may someday be used as primary support, because the flexibility of cable may be amenable to automated installation in mid to low-seam coal mines.

- **Wide Load/Deformation Range Capability -** Normally, cables have more deformation (or stretch) than traditional roof bolts. Common cable bolts and grout length (3.66 m (12 ft) cable with 1.52 m (5 ft) of resin grout) will be at "yield" at about 1.9 cm (3/4 in) of deformation, yet will continue to slightly build load and deform to 7.6 to 10.16 cm (3 to 4 in) of deformation (see figure on p. 3). This performance is good for many applications. By fully grouting the bolt in resin, a "stiffer" (less deformation to yield) performance can be obtained. Likewise, by varying the amount and/or type of resin, an even "softer" performance, with much more stretch and/or yield before failure, is possible.

The "cable bolt system" comprises both the cable bolt and the resin anchorage. Cable bolts vary from manufacturer to manufacturer; however, most cable supports incorporate several basic components:

- Termination - A variety of systems are used to attach a head to the cable strand. Both passive and tensionable systems are available. The head typically bears on a heavy plate (or strap) installed against the mine roof.

- Cable - The most common cable in use today is a seven-wire, 1.524-cm (0.6-in) diameter, ASTM grade 270 strand.

- Anchors - Most manufacturers of cable bolts provide some form of cable anchor to promote resin mixing and to enhance the ability of the cable to anchor in the resin column. A variety of anchors are available, including nut cages, buttons, bird cages, and bulbs.

CABLE BOLT ADVANTAGES

- Greater support
- Fewer injuries
- Deformation
- Secondary support
- Reduced costs
- Ventilation
- Flexibility
- Improved miner safety

Greater Support Strength - The typical 7 strand cable bolt noted previously will typically yield at about 25.4 metric tons (28 short tons) and not fail until about 29 metric tons (32 short tons) (see figure below). This is more than most roof bolts, giving high support resistance per support. A converse benefit for many secondary support applications is that cable bolts will eventually fail unlike some wood supports, which hardly ever fail. This may be advantageous for some secondary support applications (*see In the Field, p. 4*).

Lower Labor/Material Costs - The cost and scarcity of timber have been a driving force in the development and use of new secondary support system technologies, especially for western U.S. longwall operations. Foremost, among these technologies is cable bolting, which has replaced wood cribs as the main tailgate support in several western mines. With the application of cable bolting, a 40% reduction in direct labor and material costs can be achieved over that of timber cribs. Much prime forest land is also potentially preserved.

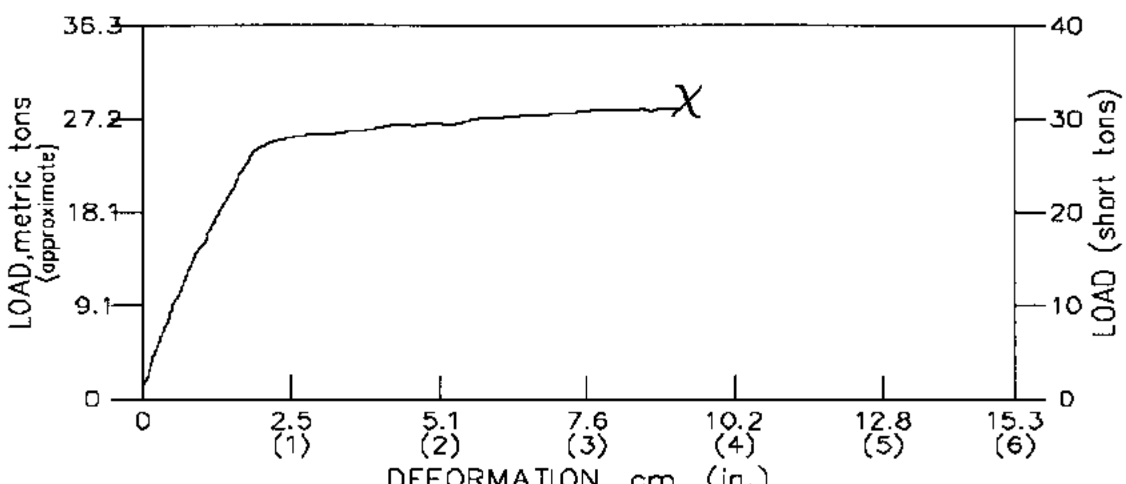
Prevention of Injuries - Originally, a reason for conducting health and safety research on cable bolts was the large number of injuries that occur from the handling of timbers and cribs. Such injuries cause human suffering and can be very expensive to a mining operation because of lost-time injuries and worker compensation claims. Cable bolts greatly reduce this type of injuries. From an operational standpoint, cable bolts reduce the amount of material that has to be stored and transported underground by 70% to 80% when compared to using timber cribs. This frees up equipment and also reduces road traffic and maintenance.

Improved Ventilation/Escapeways - Ventilation is also improved with cable bolts. Studies have shown that the resistance to ventilation from wood cribs was decreased by 25% when cable bolts were used. This reduction in resistance has a positive impact on dust control as well as ventilation costs. The improvement in ventilation becomes extremely important when designing a super longwall panel where cable bolts may be the key to the successful operation of these super panels. With a cribless gate road, the use of the tailgate as an escapeway is greatly enhanced. Walking through the restricted space between the cribs is eliminated, while exiting the face does not require climbing over and around the tailgate entry. This also provides greater clearance for supplying and maintaining the face and tailpiece.

Flexibility - Because cable bolts are flexible, long supports can be installed very quickly and easily in limited seam height.

Enhanced Miner Safety - Many of the above advantages combine to provide better working conditions. Obviously, the support strength of cable bolts, improved ventilation, and reductions in dust and materials handling injuries serve to improve health and safety conditions for the miner.

Investigators include:
Thomas P. Mucho at 412-892-6558
Dennis R. Dolinar at 412-892-6549
Lewis A. Martin 509-484-1610



Cribs Versus Cables

By Thomas P. Mucho

A field site in the Eagle Coalbed served as the first full-scale test of a cable bolted cribless tailgate on a longwall in the eastern United States. The Pittsburgh Research Center completed this initial test in December 1995 at a mine in southern West Virginia. Previously, most cribless cable bolt test areas and usage had been in the Western United States. Generally, the immediate roof in the mine changes from a sandstone to shale. In the study area, the immediate roof consisted of massive, but small (45.7 cm - 61 cm (18 in - 24 in)) sandstone layers separated by thin coal streaks. Primary roof support was 1.07 m (3.5 ft), grade 60, No. 6 resin bolts installed on 1.52-m (5-ft) centers using T-2 channels. Cables were 3.66 m (12 ft) with 1.52 m (5 ft) of resin anchorage in rows of 1.2 m (4 ft) on 1.8 m (6 ft) centers. Intentions were to locate the test site in what could be anticipated to be the worst ground conditions along the longwall panel within a given timeframe. As a result, the study site was positioned under a stream valley that had been associated with past ground control problems. The site was also under a longwall barrier pillar in the Upper Powellton Coalbed that had been previously mined.

In this study, cable bolts proved more than adequate to provide a stable cribless tailgate. Other advantages and possibly some disadvantages were also noted compared to cribs.

The field instrumentation used was–

- Multipoint sonic probe roof extensometers (extos) to measure roof movements.
- Hydraulic and pressure pads on cable bolts to measure support loading.
- Roof/floor convergence pins to measure bottom heave (roof movements known from extos).
- Automated data collection system for extos a first in cooperation with the Canada Centre for Mineral and Energy Technology (the Pittsburgh Research Center has since purchased its own similar unit).

The cable bolts and instrumentation were installed just prior to the adjacent longwall face passing the test area, enabling the recording of the side abutment loading effects from the panel. There was very little roof movement during and after the passing of the adjacent longwall face. However, there was considerable bottom heave (inches) in the crib areas as opposed to almost no heave in the cable bolted area (tenths of an inch). This same pattern, more bottom heave in the crib area, was also true of the floor heave resulting from the front abutment during the panel longwall mining. We were never able to ascertain the reason for this difference in behavior.

The tailgate roof in the cable bolted area was extremely stable during the longwall mining with only a total of one tenth of an inch of total movement over the approximately 6.1 m (20 ft) monitored with the extensometers, even for those read up to 10.4 m (34 ft) inby the longwall face. The cribbed area was also reasonably stable with a maximum of a little over 1.27 cm (1/2 in) of total movement in the roof in an extensometer. The extreme stability in the cable area was also noted by the low cable bolt loads, almost none until the face passed, and generally only a few thousand pounds gained until they passed the end of the shield caving beam. Crib convergence, and therefore loading, was also low, mainly increasing because of the bottom heave of the longwall front abutment loading.

Although roof stability was relatively the same, stable in both the cribbed and cabled areas, there were some notable differences in caving characteristics between the two support types. The cables would support the tailgate entry to distances of approximately 22.9 m (75 ft) behind the longwall face. They would then begin to fail in a domino fashion until the resulting fall would approach near the inby end of the shield caving beam. This cyclic caving was noted throughout the cable area. Also, caving would be nearly complete to the edge of the tailgate chain pillar. In contrast, crib caving, while also cyclic, would usually be in periods of hundreds of feet. Also, all of the cribs would not fail, especially not the line nearest the chain pillar. This difference in caving characteristics resulted in less front abutment loading on the longwall panel and tailgate through the cable area compared with the cribbed areas. This was evidenced by tailgate rib sloughage, tailgate area panel coal sloughage, and roof noise in the tailgate. There can be pros and cons to these differences in behavior.

Likewise, the differences in caving behavior produced an impact on face ventilation. Because of the tighter caving in the cable test area, almost all of the longwall air traveled along the face with little traveling behind the shields, especially in the tailgate area. Tailgate gob ventilation was also reduced. This may unfavorably impact gassy gob longwalls, but should be a plus for longwall dust control due to higher face air utilization for dust removal.

A further evaluation of tailgate cable bolts in weak roof conditions for comparison with this strong roof environment is expected to be the next phase of this work by the Pittsburgh Research Center.

OUT OF THE LAB

Shield Failure Results

By Thomas M. Barczak

As a result of these performance tests, it was determined that the shield could be safely used for several more panels.

The decision to scrap a set of longwall shields and purchase new ones has a major impact on the safety and productivity of a longwall operation. That decision is most often based on the structural integrity of the existing shields. Shield failure will eventually stop a longwall operation, and the repairs are typically costly and ineffective. Ideally, shields should be replaced after full life expectancy is reached.

The life of a shield is determined by the number of operating cycles and the in-service load conditions. Structural failures are typically due to fatigue. Shield fatigue failure is as subtle as a time bomb, exploding with little or no warning. Performance testing is the only practical method of determining the remaining life expectancy of shields. The optimum time for testing is when the in-service, utilization approaches the manufacturer's warranty.

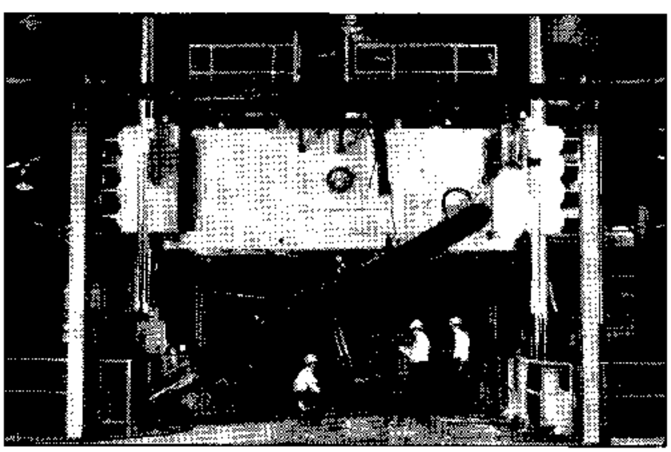
The Strategic Structures Testing Laboratory in Pittsburgh, PA, with its unique Mine Roof Simulator is an active load frame that more accurately simulates in-service load conditions than static load frames. This is the sole active load frame in the United States with sufficient size and load capacity to accommodate shield testing. The Mine Roof Simulator provides realistic performance data by combining both vertical and horizontal (racking) loading into a single load cycle. In a static frame, several load cycles are needed to obtain this loading. In addition to these advantages, an independent assessment of shield performance is guaranteed.

Recently, Eastern Associated Coal Co. evaluated the life expectancy of shields that were in service for nearly 15 years with approximately 40,000 load cycles of use. The Mine Roof Simulator performance test applied 10,000 cycles of combined vertical and horizontal loading with strain gauges used to measure the load transfer to each of the shield components.

In-service load conditions tested

- *Slippage of the canopy along the roof interface, which transferred the horizontal component of the leg force to the caving shield-lemniscate assembly.*
- *Flexing of the canopy and base by compaction of roof-and-floor debris.*
- *Eccentric face-to-face racking of the canopy relative to the base, which produced lateral forces and bending.*

The shield maintained its integrity during the tests with no apparent structural damage.



Shield testing at the Mine Roof Simulator.

Mine Roof Simulator Capabilities

	FORCE	STROKE
Vertical Z	14 MN (3,000,000 lbs)	600 mm (24 inches)
Horizontal X	**7.3 MN (1,600,000 lbs)**	**400 mm (16 inches)**
Lateral Y	7.3 MN (1,600,000 lbs)	12 mm (0.5 inches)
	DIMENSIONS	
Platen Size:	**6.1 x 6.1 meters (20 ft x 20 ft)**	
Simulator Weight:	907 metric tons (2,000,000 lbs)	

RESEARCH PROFILES

Multiple-Seam Mining

By Gregory J. Chekan

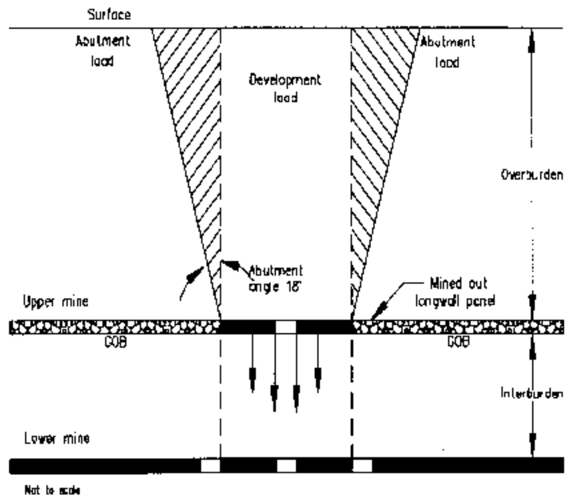
The Clean Air Act of 1992 required lower sulfur dioxide emissions, increasing demand for low-sulfur coal. Some of the major low-sulfur coalbeds in the Appalachian Coal Region occur at depths ranging from 152.4 m to 609.6 m (500 to 2,000 ft). Historically, coal in this region has been mined without consideration for the influence on other adjacent coalbeds. As a consequence of this practice, environmentally acceptable compliance coal may be more difficult to mine because of ground control problems associated with multiple-seam mining. Developing design technology or models to safely mine coal above or below an existing mine provides an economic and employment opportunity and a domestic source for U.S. energy requirements.

Multiple-seam mining requires a comprehensive understanding of the stress transfer that occurs between two coalbeds. Obviously, mine design is crucial for roof, rib, and floor stability. Pillar and entry dimensions, positioning, as well as the timing during mine development, affect overall conditions in the mines.

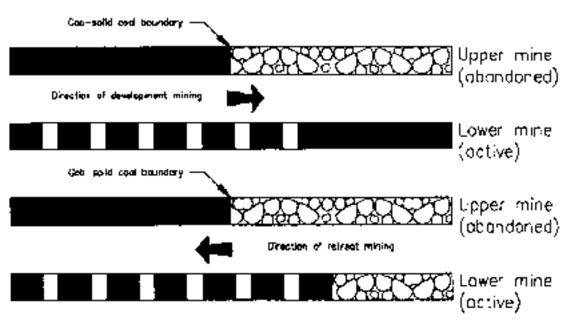
Multiple-seam mining research, for the most part, has concentrated on two areas. The first area constitutes the bulk of the research to date and involves the analysis of field data. These empirical studies involved observation or use of geomechanical instrumentation to gather data leading to descriptive conclusions of ground problems and design recommendations for improving operation stability. Empirical studies based on case study documentation have revealed the factors under which interactions of the coalbeds are most likely to occur. These studies showed that both geology and mine design influence interactive distance, magnitude, and location.

Other multiple-seam research involves the use of numerical methods for predicting interactive problems. These methods combine case study results with theoretical and statistical analysis in attempting to develop optimum mining plans for multiple-seam conditions. Photoelastic and numerical models have provided insight and improved understanding of mining-induced stress and interactions with other workings. Numerical models can also simulate relative stress distribution and transfer under varied design parameters or conditions.

Health and safety research has provided practical information and guidelines on multiple-seam design for both longwall and room-and-pillar mining. For instance, a method was developed to assist operators size lower-seam gate road pillars when superpositioning is practiced in longwall mining, as shown below.



In room-and-pillar operations, high stress zones are usually encountered in the lower mine when mining beneath an isolated barrier pillar or a gob-solid coal boundary in the upper mine. To reduce stress in the lower mine pillars, retreat mine from the gob to the solid side of the boundary and support the barrier edge with a row of pillars, as shown below.



Information Circulars 9360 and 9403 provide more detail on multiple-seam research. For a copy of these reports or additional information, call Greg Chekan at (412) 892-6749 or Dave Ingram at (412) 892-6547.

FROM THE WEST

Deep Mine Stress

By Doug Scott

Future domestic mining will expand to deep-level mining because of environmental constraints and depletion of readily accessible, currently mined, near-surface, low-grade deposits.

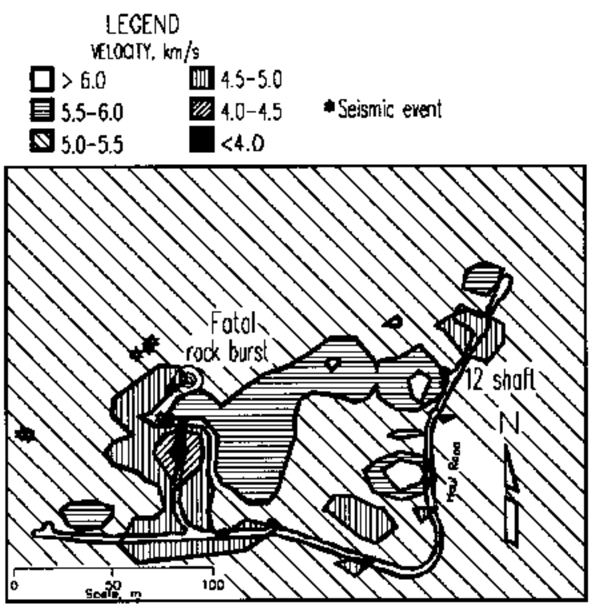
Rock masses in deep-level mines are subject to high stress, which can result in unexpected failure of rock into mined-out openings. Many factors, including but not limited to geology, rate of mining, geometry of mine openings, and tectonic stress, can be evaluated to determine ground conditions prior to failure.

One method to evaluate relative stress in underground rock masses is to use "seismic tomography," based on the principle that highly stressed rock will demonstrate relatively higher seismic velocities than rock with less stress (load).

Personnel at the Spokane Research Center have been investigating the use of seismic tomography to identify stress in remnant ore pillars in deep greater than 1,220 m (4.003 ft) underground mines. In this process, three-dimensional seismic surveys are conducted in a pillar between mine levels. A sledgehammer is used to generate P-waves, which are recorded by geophones connected to a stacking signal seismograph capable of collecting and storing the P-wave data. Travel times are input into a spreadsheet and then merged into imaging software. Mine workings are superimposed over P-wave velocity contours to generate a tomographic image.

The success of using tomographic technology to determine stress and geologic structure in an underground pillar depends on subsequent surveys to be used for comparison with earlier surveys. A drop in stress, increase in stress, or movement of stress can be verified by comparing tomograms. Seismic tomography has been proven to be a successful method to delineate stress in underground pillars and can be implemented by mine engineers.

The overall importance of this work is to improve the safety of miners working in deep-level mines. Environmental constraints imposed on surface mining and depletion of currently mined low-grade near-surface deposits will certainly force the mining of deep-level domestic deposits. Determining new methods to analyze stress in rock masses in deep-level mines by the Spokane Research Center will contribute to the future of a safe working environment for miners.



For more information on noninvasive geophysical techniques for dynamically detecting hazards during active mining, call Doug Scott at 509-484-1610

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UPDATE MINING HEALTH AND SAFETY

INTERVIEW
Miklos D. G. Salamon

Exclusive

In a career that has spanned more than 3 decades, Dr. Salamon is a world-renowned expert in mining engineering. Recently, he has served as the Head of the Mining Engineering Department at the Colorado School of Mines and as the Director of the Colorado Mining and Mineral Research Institute. Dr. Salamon's expertise in the field of rock mechanics, mine safety, advanced mining technology, and mining research management continues to be sought worldwide from Australia to Zimbabwe. Below are his thought-provoking comments on ground control.

From your perspective as a ground control engineer and professor of mining engineering, which are the most pressing areas where the technology of ground control should be improved?

I suggest that there are at least three areas which require urgent attention. First, we need to improve our definition of the constitutive laws in the postfailure state. Second, we should enhance our capability of quantifying the properties of the rock mass in the field, mainly to provide imput parameters for modeling. Third, we must rekindle our efforts to perform systematic field observations and compare the derived data with results obtained by numerical modeling. We should not hesitate to do back-calculations to make the model more useful.

There are many fundamental changes occurring in the mining industry at this time. How do you see ground control research occurring in the future?

The ability to carry out large-scale ground control research has virtually disappeared. The effort required to tackle the tasks I described in the previous question is probably beyond the means of the surviving research units in academia, in government service, or in industry. I really do not know where we go from here. It is even more perturbing that, apart from a few bright spots, the situation is not better worldwide.

You have worked on mining problems in numerous countries around the globe. How do you assess the present state of ground control technology and its worldwide impact on mining operations?

While major strides have been made, I feel disappointed with the rate of advance. The slow rate of progress is probably commensurate with the magnitude of the task and with the fragmented research which has lacked coordination and perseverance. The impact on industry has been spotty. In some countries, the technology is being implemented in an acceptable manner, while in others, there is a surprising lack of awareness by engineers of the availability of better and safer methods of ground control.

"The ability to carry out large-scale ground control research has virtually disappeared."

What major factors or events do you believe have helped to shape ground control technology around the world?

The development of ground control has been shaped largely by pressing needs, which manifest themselves either as recurring severe problems or major disasters. The rockburst problem in deep South African gold mines is a striking example of the persistent problems. The annual toll resulting from the bursts has inspired an unprecedented research effort that resulted in significant advances. The Coalbrook Colliery pillar collapse in 1960, costing the life of 437 persons, is a tragic illustration of the catastrophic events that has motivated significant research expenditures and defined its priorities.

You were the coauthor of the pillar design method used in South African coal mines since 1967. What factors helped to make that pillar design method acceptable to the industry?

I think there were four factors. First and foremost, the design approach was introduced in the aftermath of the Coalbrook disaster. Everyone wished to avoid the recurrence of such a tragedy. Secondly, the method was based on the strict statistical analysis of some 125 case histories, of which 27 were previous pillar failures and the remainder were stable cases. The use of these data lent considerable authenticity to the results. Thirdly, a lot of engineers were involved in the collation of the data forming the basis of the study. This participation had created a feeling of "ownership" which made the introduction much easier. Finally, we, the originators of the design method, made every effort to explain the principles and participated on an industry-wide scale in its actual application.

"We must rekindle our efforts to perform systematic field observations and compare the derived data with results obtained by numerical modeling."

Please remember to return the reply mail postcard

Thank You!

In the 1960's you were instrumental in developing some of the first analytical, analog, and numerical models of mines; however, it appears that even now empirical formulas and rules of thumb still guide most practical ground control decisions. What do you feel is the present utility of mechanistic models, and is there a hope for change in this area?

This is a very complex and multifaceted question. I will attempt to tackle only some of these complexities. Let me at the outset say that mechanistic models are fairly widely used in the mines where they were initially introduced, that is, in the South African gold mines. Their relative lack of success on the international scene is partly due to our rapidly growing ability of developing more and more intricate models, often without testing them against the behavior of the prototype. The complexity of the models has outpaced our ability of quantifying the representative properties for the rock mass. Another problem is the lack of communication between the model developers and the engineers at the mines with problems. I am convinced, however, that some of the already available models, while not capable of achieving miracles, are able to do much more than they are given credit for. Let us give them a chance.

STARTUPS

Underground Stone Mining

By Lou Prosser

To date, very little research has been directed toward underground stone mining. Data analysis shows that a disproportionate number of fatalities occurred in underground U.S. limestone mines compared to the quantity of stone produced. In the last 10 years, production of limestone from underground mines accounted for about 5% of the U.S. total output but 24% of that industry's fatalities. Since 1985, 11 miners have been killed and 9 injured in ground control-related accidents.

As an indication of growing interest in this area, 177 participants attended a Ground Control Seminar for underground stone mines on November 1, 1995, in Somerset, PA. The meeting was sponsored by the Pennsylvania Bureau of Deep Mine Safety and the Mine Safety and Health Administration.

About 85% of the mining company personnel in attendance responded to a survey on conditions and areas of interest to the industry. Results of the survey showed that 70% of the operators use roof bolts on a spot or as-needed basis; about 20% bolt regularly or throughout their mine. High interest was expressed in miner training in the following areas: scaling (77%); bolting (67)%; and blasting and drilling (both at 49%). As a result of this initial interest by industry and a trend of increasing underground stone production, a more detailed examination of factors that influence ground conditions in this industry is planned for 1996. If you are interested in more information on this project, please let us know.

Investigators include: Anthony Iannacchione 412-892-6581, Roy Grau 412-892-6562, and Lou Prosser 412-892-4423. All three can be reached by fax at 412-892-6891.

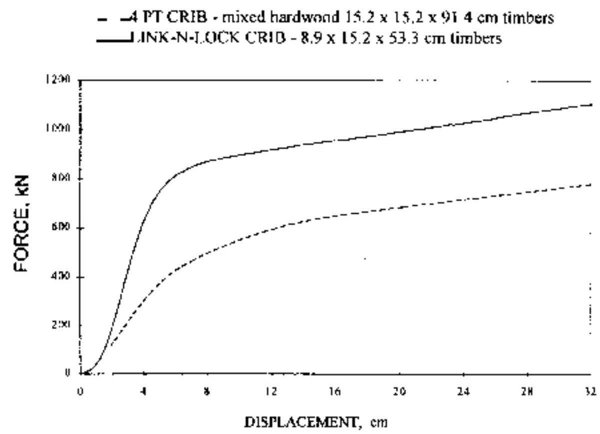
NEW CONCEPTS

LINK-N-LOCK cribs provide higher support capacity with less wood. These cribs, developed and manufactured by Strata Products (USA) Inc., improve the capability of conventional wood cribbing. The Link-N-Lock is constructed from timber blocks that are notched on both ends such that they stack much like a log cabin. This arangement provides full contact among adjoining timbers as opposed to 40% contact provided in conventional 4-point cribbing stacks.

This concept provides greater support capacity, improves stability, and reduces material handling by 30% or more. These supports are ideal for bleeder entries and other long-term support areas. For more specifics on our assessment and testing of the Link-N-Lock cribs, call Tom Barczak at 412-892-6557 or fax your inquiry to 412-892-6891.

Reference to specific products does not imply endorsement by the Pittsburgh and Spokane Research Centers.

COMPARISON OF STRATA PRODUCTS LINK-N-LOCK CRIB SUPPORTS AND CONVENTIONAL 4-POINT CRIB



COMPUTER CORNER

Mining Software

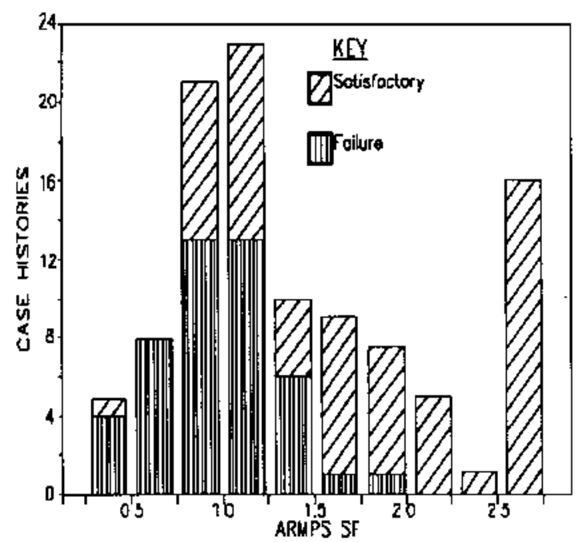
Retreat Mining Pillar Stability

By Christopher Mark

Room-and-pillar retreat mining has been growing in popularity because of productive new technology, including remote control continuous miners, extended cuts, and mobile roof supports. Pillar retreat mines can achieve the same high recovery as longwalls, with lower capital costs and greater flexibility. Unfortunately, between 1990 and 1995, nearly 30% of all roof/rib fatalities occurred on retreat mining sections. Also, millions of tons of minable coal are left in place each year because of pillar squeezes, floor heave, pillar line roof falls, and pillar bumps. Traditional pillar design methods are of little help due to the complex mining geometries and abutment pressures that are present during pillar extraction.

The Analysis of Retreat Mining Pillar Stability (ARMPS) program was developed to help ensure that pillars are of adequate size for all anticipated loading conditions. ARMPS calculates a Stability Factor (SF) based on estimates of the loads applied to, and the load-bearing capacities of, pillars during retreat mining operations. The program can model the significant features of most retreat mining layouts, including angled crosscuts, varied spacings between entries, barrier pillars between the active section and old (side) gobs, and slabcuts in the barriers on retreat. It also uses the Mark-Bieniawski pillar strength formula (discussed in Facts and Formulas, p. 11), which considers the greater strength of rectangular pillars.

Histogram of the ARMPS retreat mining case history database, showing pillar failures and satisfactory cases.



To obtain a single copy of the ARMPS computer program, send a double-sided, double-density diskette to:
Christopher Mark
P.O. Box 18070
Pittsburgh, PA 15236

The ARMPS method is being verified through analysis of past pillar recovery case histories. To date, 105 case histories have been obtained from 10 States. As the figure on p. 10 shows, pillar failures occurred in 92% of the cases where the ARMPS SF was less than 0.75. Where the ARMPS SF was greater than 1.5, 95% of the pillar designs were satisfactory. SF values ranging from 0.75 to 1.50 show mixed results, as both successful and unsuccessful cases are found.

Current research is directed toward determining which factors may contribute to satisfactory conditions when the ARMPS SF is in the 0.75 and 1.5 range.

The ARMPS program is a proven aid in planning pillar recovery operations. It is easy to use and provides analysis in a relatively short time. ARMPS is currently in use at mines in Kentucky, Pennsylvania, Tennessee, and West Virginia, and regulatory agencies have also made extensive use of the program. ARMPS is just one aspect of current health and safety research directed toward improving the safety of room-and-pillar retreat mining. Other issues that are being addressed include preventing massive pillar collapses/airblasts, the design of retreat panels for bump control, and the application of mobile roof supports.

Facts and Formulas

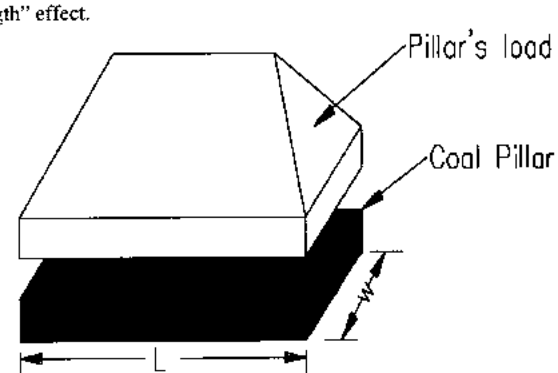
Rectangular Pillar Formula

Most pillar strength formulas were developed for square coal pillars. An example is the Bieniawski formula:

$$S_p = S_1\,[0.64 + (0.36\ w/h)], \qquad (1)$$

where S_p = pillar strength,
S_1 = in situ coal strength,
w = pillar width (least plan dimension), and
h = pillar height.

Bieniawski recognized that his formula underestimated the strength of rectangular pillars, but because it was based on in situ testing of square specimens, there was no obvious way of estimating the "pillar length" effect.



RECTANGULAR PILLAR

- The Mark-Bieniawski Pillar Strength Formula considers the effect of pillar length.

Today, we know that when a pillar fails, the stress is lowest at the rib and greatest in its central core. The stress profile is the function that describes the stress level at any point between the rib and the core. The pillar's ultimate load-bearing capacity is the stress profile integrated over the area of the pillar.

The square pillar formulas do not explicitly consider the internal stress distribution, but they imply a stress gradient because of the w/h effect. The stress gradient implied by the Bieniawski square pillar formula was derived mathematically and found to be:

$$\sigma_p = S_1\,[0.64 + (2.16\ x/h)], \qquad (2)$$

where x = distance from the pillar rib, and
σ_p = pillar stress.

The Mark-Bieniawski rectangular pillar strength formula was obtained by integrating equation (2) over the area of a rectangular-shaped pillar, then dividing by the load-bearing area:

$$S_p = S_1\,[0.64 + (0.54\ w/h) - (0.18\ w^2/Lh)], \qquad (3)$$

where L = pillar length.

This formula indicates that the increase in strength in a rectangular pillar depends on both (w/h) and (w/L). For example, this formula suggests that the strength of a strip pillar with a very large w/h ratio is nearly 50% greater than predicted by the original square pillar formula. A pillar whose length is twice its width is predicted to be 10%

If you have a fact, formula, or issue for discussion, let us know by phone or fax.

DATA LINE

Mining Fatalities

	1993	1994	1995
TOTAL	98	84	98
Coal	47	44	47
Surface	21	20	19
Underground	26	24	28
Metal/ Nonmetal	51	40	51
Surface	33	31	45
Underground	18	9	6

As of March 8, 1996, 7 fatalities occurred in coal and 7 in metal/nonmetal compared to 3 and 9, respectively, for the same time in 1995.

Source: Mine Safety & Health Administration.

COAL PRODUCTION
1995
Top 15 States
(million tons)

		Short	Metric
1.	Wyoming	263.7	239.2
2.	West Virginia	162.9	147.8
3.	Kentucky	150.6	136.6
4.	Pennsylvania[1]	57.9	52.5
5.	Texas	49.5	44.9
6.	Illinois	47.9	43.5
7.	Montana	37.4	33.9
8.	Virginia	34.6	31.4
9.	North Dakota	29.7	26.9
10.	New Mexico	26.8	24.3
11.	Alabama	26.1	23.7
12.	Indiana	25.7	23.3
13	Utah	25.0	22.7
14.	Colorado	24.4	22.1

[1]Excludes anthracite.

Source: U.S. Department of Energy, Energy Information Administration, January 1996.

NEW RELEASE: "Rating the Strength of Coal Mine Roof Rocks" - IC 9444 - call Gregory Molinda at 412-892-6890 or Christopher Mark at 412-892-6522 for a copy - or fax your request to 412-892-6891.

WORKPLACE INJURIES & ILLNESSES

The Bureau of Labor Statistics released a report on workplace injuries and illnesses on December 15, 1995. For 1994, 8.4 cases of injury or illness were reported for every 100 equivalent full-time workers in private industry workplaces. The breakdown for mining is shown below.

NONFATAL OCCUPATIONAL INJURY INCIDENCE RATES PER 100 FULL-TIME WORKERS, BY INDUSTRY (1994)

Industry	Annual average employment	Total cases	Lost workday cases		Cases without lost workdays
			Total	With days away from work	
Mining (Totals)[1]	**600,000**	**6.0**	**3.8**	**3.2**	**2.2**
Metal mining	48,800	5.3	3.0	2.1	2.3
Coal mining	112,200	9.3	7.2	6.9	2.1
Oil and gas extraction	335,800	5.2	2.9	2.3	2.3
Nonmetallic minerals, except fuels	103,300	5.8	3.5	2.8	2.2

[1]Independent mining contractors are excluded from the coal, metal, and nonmetal mining industries.